

---

# **A Monitoring and Warning System for Close Geosynchronous Satellite Encounters**

**R. I. Abbot, R. Clouser  
E. W. Evans, R. Sridharan  
MIT Lincoln Laboratory**

**SPACE CONTROL CONFERENCE**

**APRIL 2001**

This work was performed under a Cooperative Research and Development Agreement between MIT/LL and GE-Americom, SATMEX, and Telesat Canada. Opinions, interpretations, conclusions, and recommendations are those of the authors and do not necessarily represent the view of the US Government.



# Outline

---

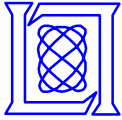
- ➔ • **Geosynchronous satellite failures**
- **Geosynchronous Monitoring and Warning System**
- **Preliminary results**
- **Summary and future work**



# Drifting Satellites in the Geopotential Well Centered at 105.3 W Longitude

---

- **Telstar 401 failed January 11, 1997**
  - Oscillates indefinitely from 97° to 115° W longitude with period ~ 800 days
  - Since failure, has encountered over 100 satellites with closest distances ~ 2 km
  - 27 close approaches predicted for 2001
- **Solidaridad 1 failed August 29, 2000**
  - Oscillates indefinitely from 101° to 109° W longitude
  - Encounters in Geopotential Well began in late January
  - 11 close approaches predicted for 2001



# Galaxy 7

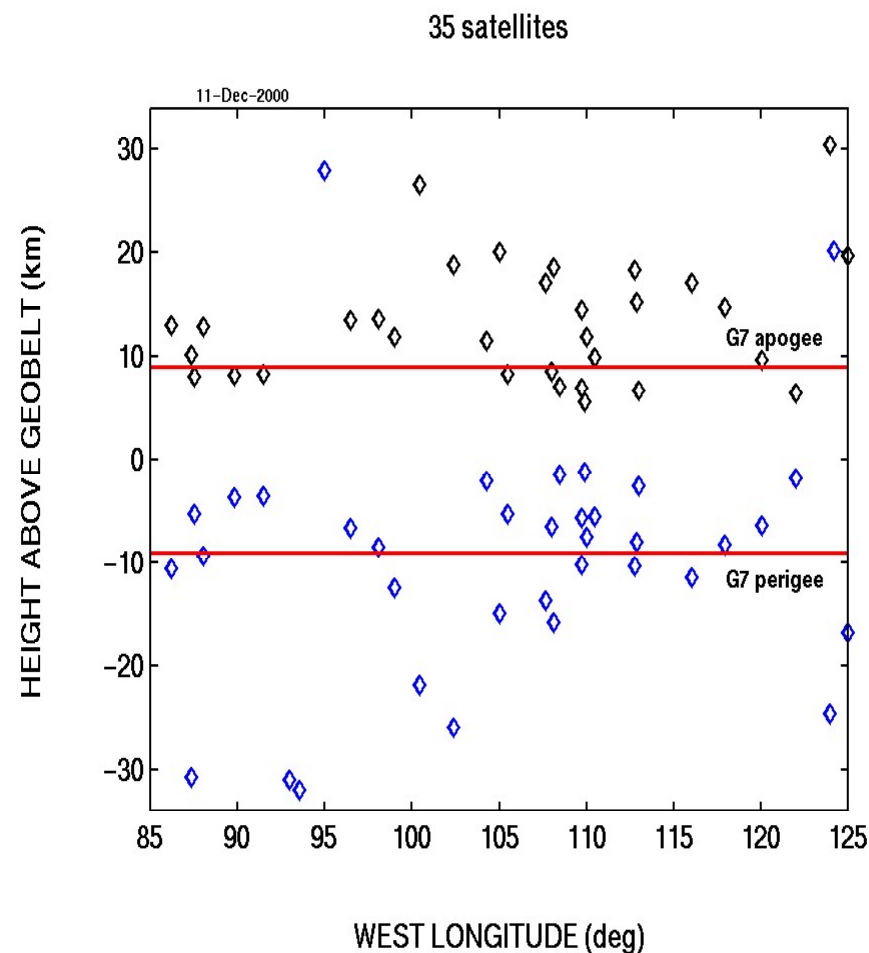
---

- **Galaxy 7 failed November 24, 2000**
- **Galaxy 7 normally oscillates in Geopotential Well from 125 to 85° W longitude**
  - It would have encountered a considerable number of satellites
- **Galaxy 7 not completely dead, thrusting capability exists**
- **Operator performed boosting maneuvers in late November**
  - Current perigee above GEO = 74 km
  - Current apogee above GEO = 286 km
  - Circulates moving West at about 2°/day
  - 26 satellites in the GEO belt are in the above Perigee to Apogee range, monitoring will look for any potential encounter

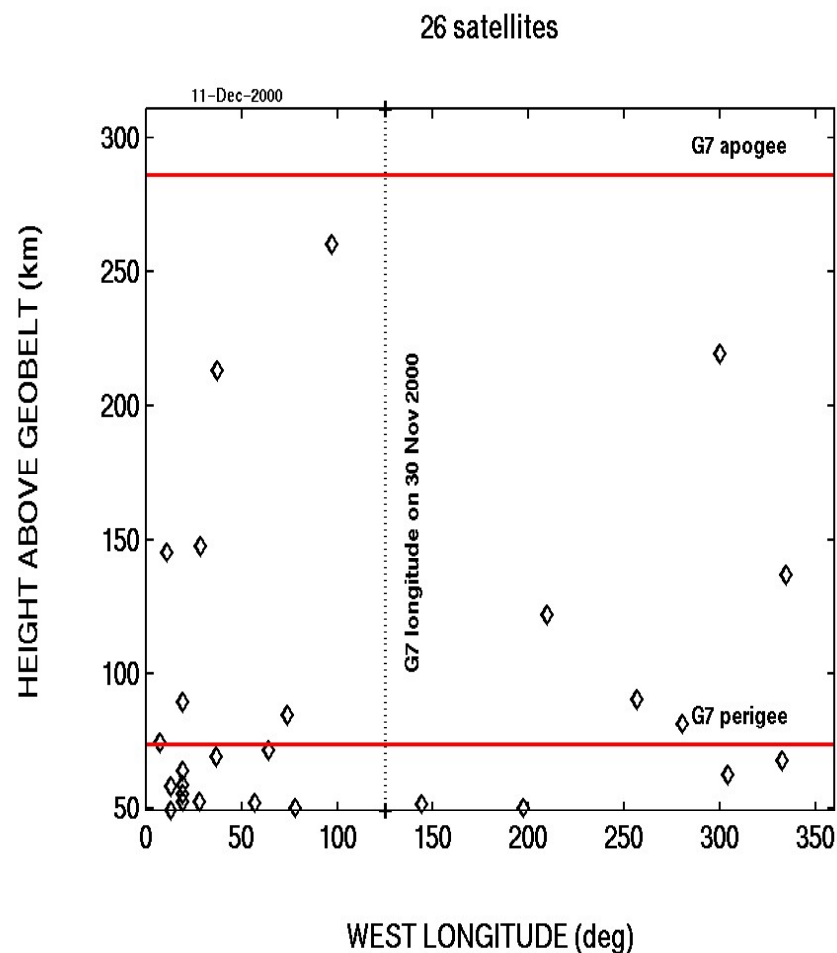


# Galaxy 7 Encounter Population Before and After Boost

Galaxy 7 vs Active Population (without boost)



Galaxy 7 vs Active Population (after boost)

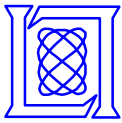




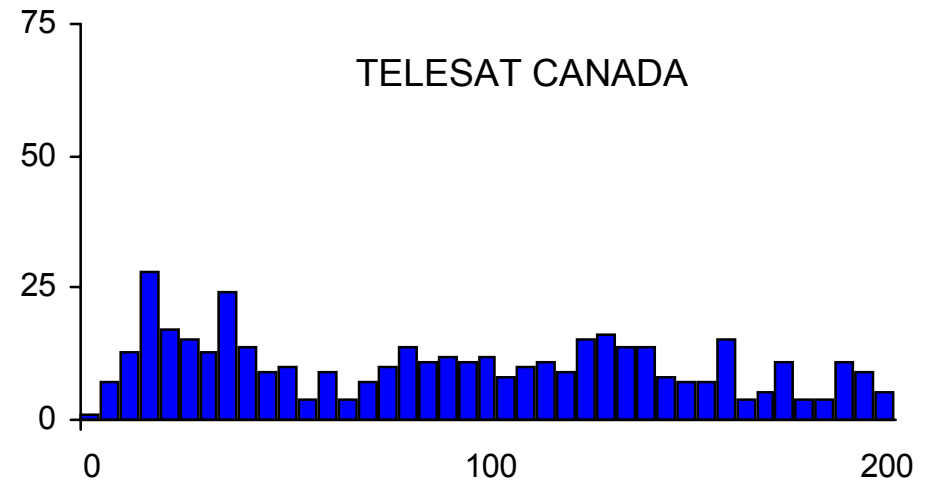
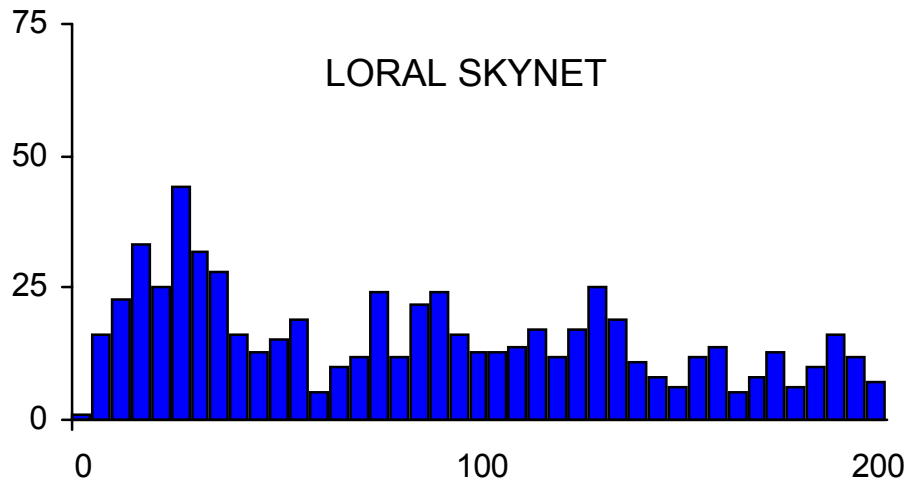
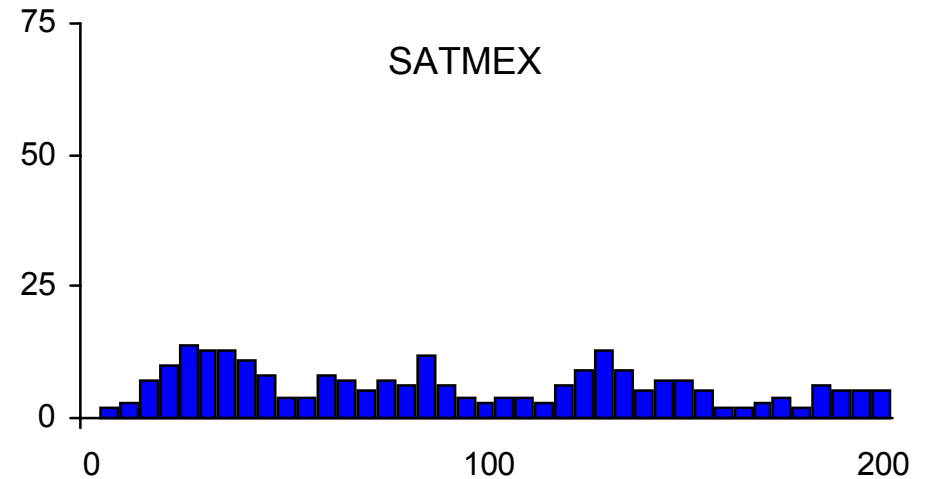
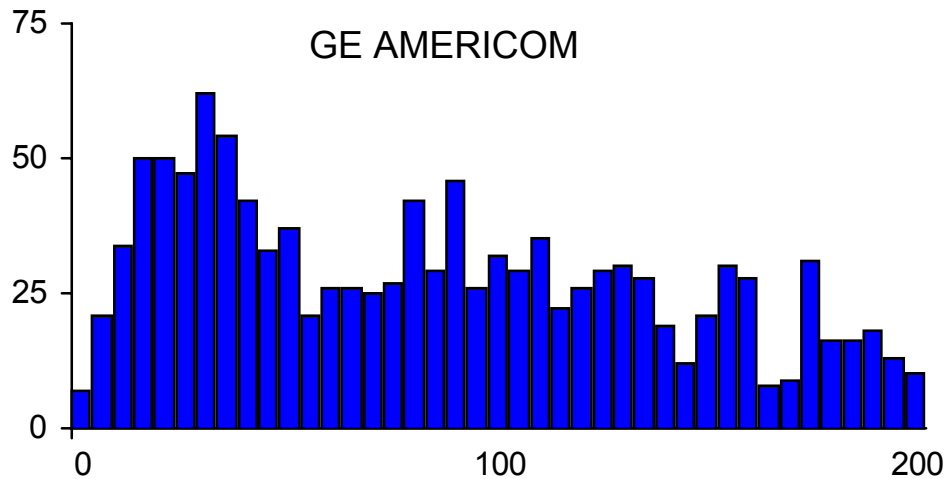
# GEA CRDA Background

---

- **MIT Lincoln Laboratory became involved in monitoring first encounters of Telstar 401 with Geopotential Well satellites**
- **Resources**
  - Millstone Hill Radar with accuracy : 5 m range, 3mm/s range rate, 5 – 10 mdeg azimuth and elevation
  - Space Based Visible telescope with 1 mdeg RA and DEC
  - High precision orbit determination DYNAMO (Force models to 1 m)
- **MIT Lincoln Laboratory established Geosynchronous Encounter Analysis Cooperative Research and Development Agreement (GEA CRDA) with commercial satellite owners/operators**
  - CRDA initially monitored the threat posed by Telstar 401, expanded to monitor threats to all CRDA partner satellites
  - GE Americom (18 Satellites), Loral Skynet (7 Satellites), SATMEX (3 Satellites), TELESAT Canada (6 Satellites)
- **Operational aspect of CRDA**
  - Monitor encounters of CRDA satellites with threatening RSOs
  - Calibrate CRDA partner range data either by processing the range data or providing high accuracy element sets to partners



# Estimated Encounters vs. Distance of Closest Approach for 2001





# Outline

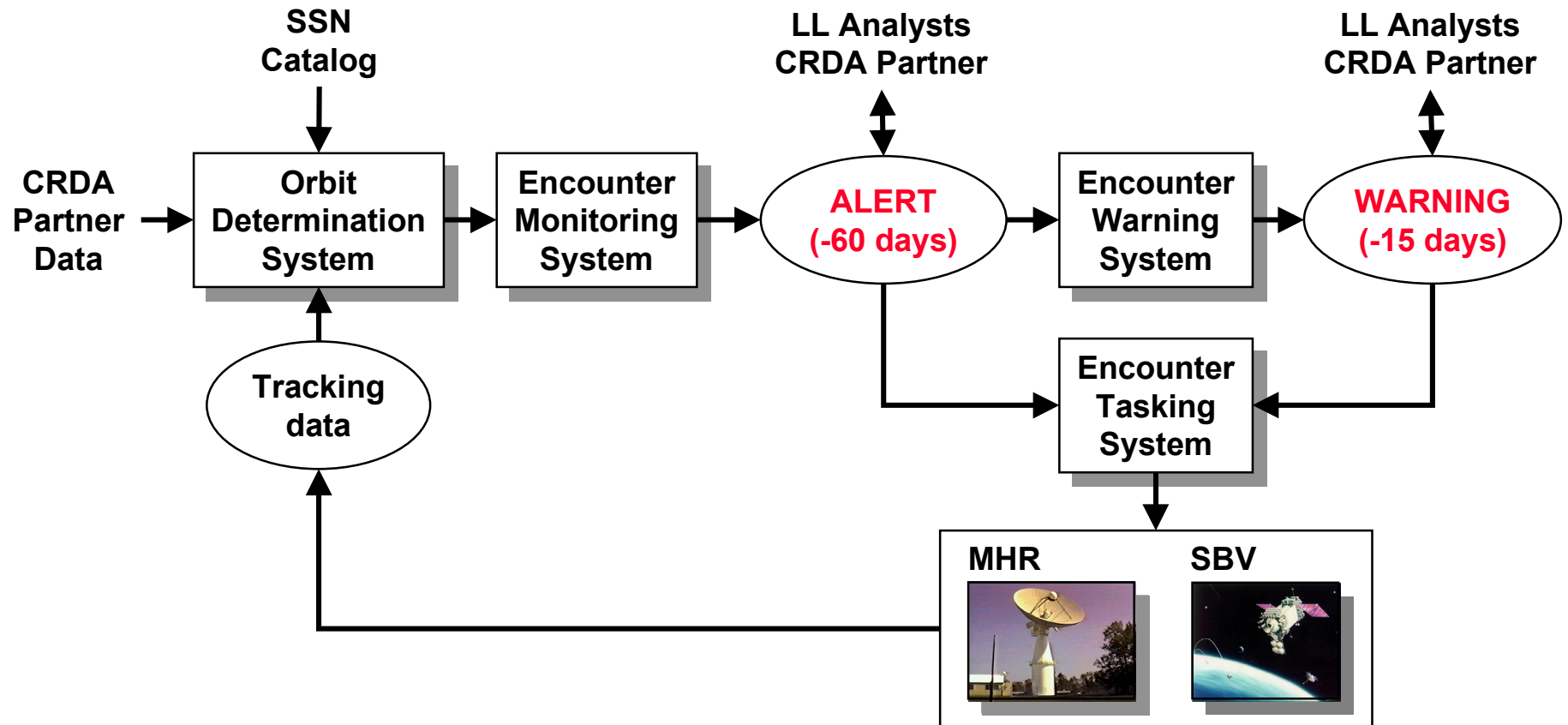
---

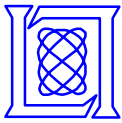
- **Geosynchronous satellite failures**
- ➔ • **Geosynchronous Monitoring and Warning System**
- **Preliminary results**
- **Summary and future work**



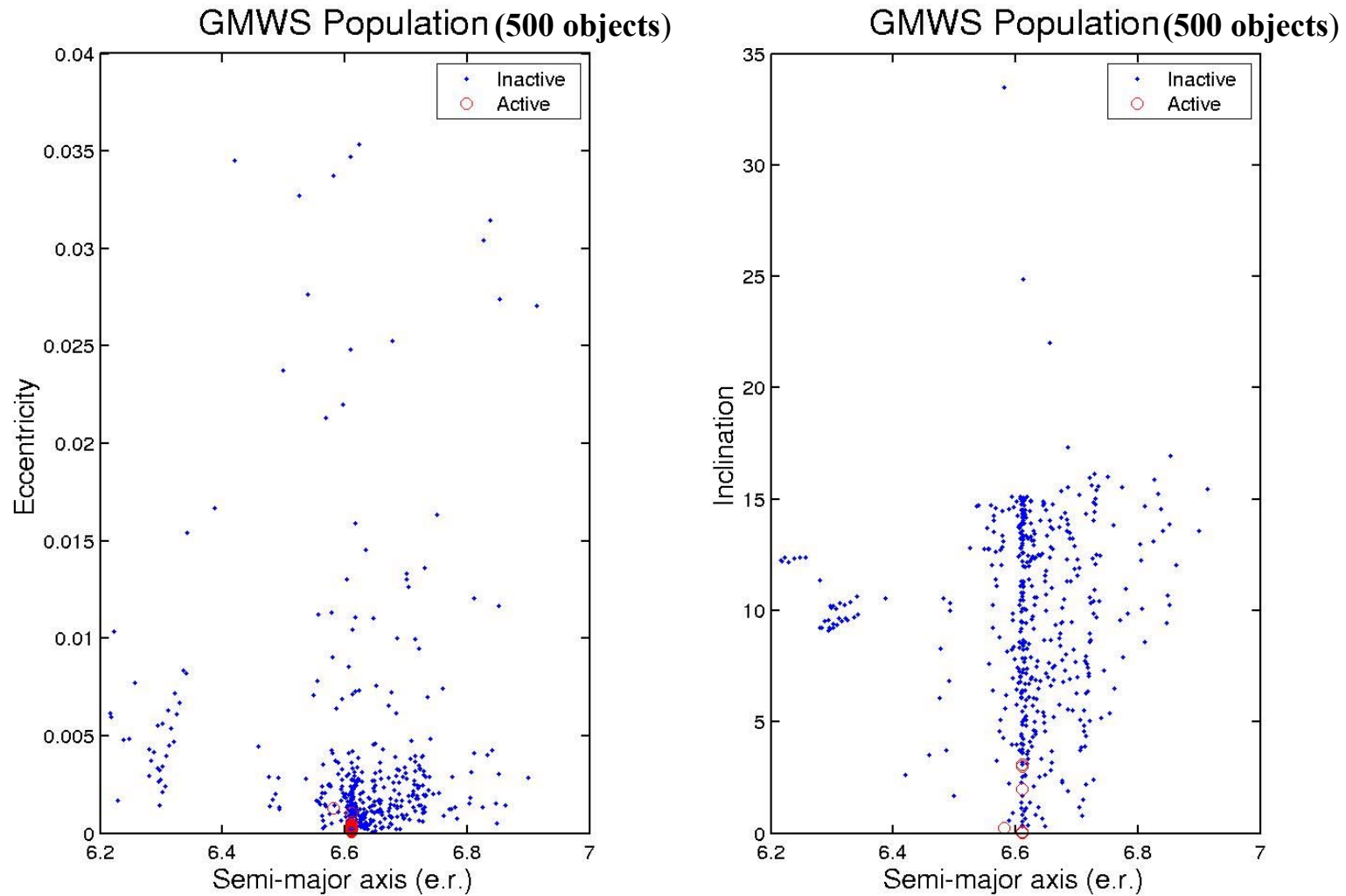


# Geosynchronous Monitoring and Warning System (GMWS)





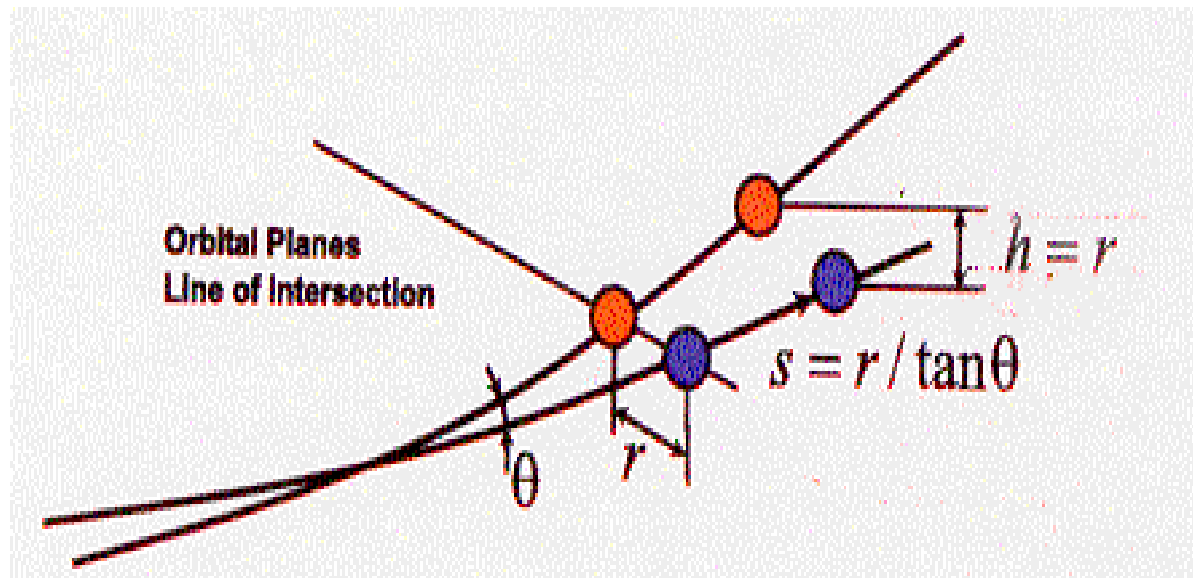
# GMWS Population





# Encounter Determination for ALERTS (1)

- **ALERTS determines encounters based on orbital plane intersection of two objects**
  - $|a_1 - a_2| \leq a_1 e_1 + a_2 e_2$  requires Perigee of one object to be greater than the Apogee of the other (necessary but not sufficient condition)
  - Orbit planes are generally inclined, an object threatening the GEO belt must cross the equator near GEO radius
  - Due to typical sizes of GEO satellites an encounter is localized to point at which orbital planes intersect





## Encounter Determination for ALERTS (2)

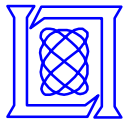
---

- Objects also need to be at point of intersection at same time
- At time one object is at point of intersection, compute longitudes and radial distances of both and check:

$$\left| L_2 - L_1 \right| \leq L_{threshold} \quad \left| r_2 - r_1 \right| \leq r_{threshold}$$

where  $L_{threshold} = 0.05$  degrees

$$R_{threshold} = 50km$$



# Encounter Determination for WARNINGS

---

**WARNINGS determine encounters based on 15 day DYNAMO ephemeris**

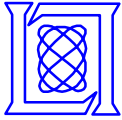
- **DYNAMO orbit propagated 15 days in ECI coordinates at 60 s spacing**
- **ECI vectors differenced, transformed to Radial, Along Track, and Cross Track Differences to show encounter distances in physically meaningful components**
- **Encounters tabulated and prioritized for tasking**



# Outline

---

- **Geosynchronous satellite failures**
- **Geosynchronous Monitoring and Warning System**
- • **Preliminary results**
- **Summary and future work**



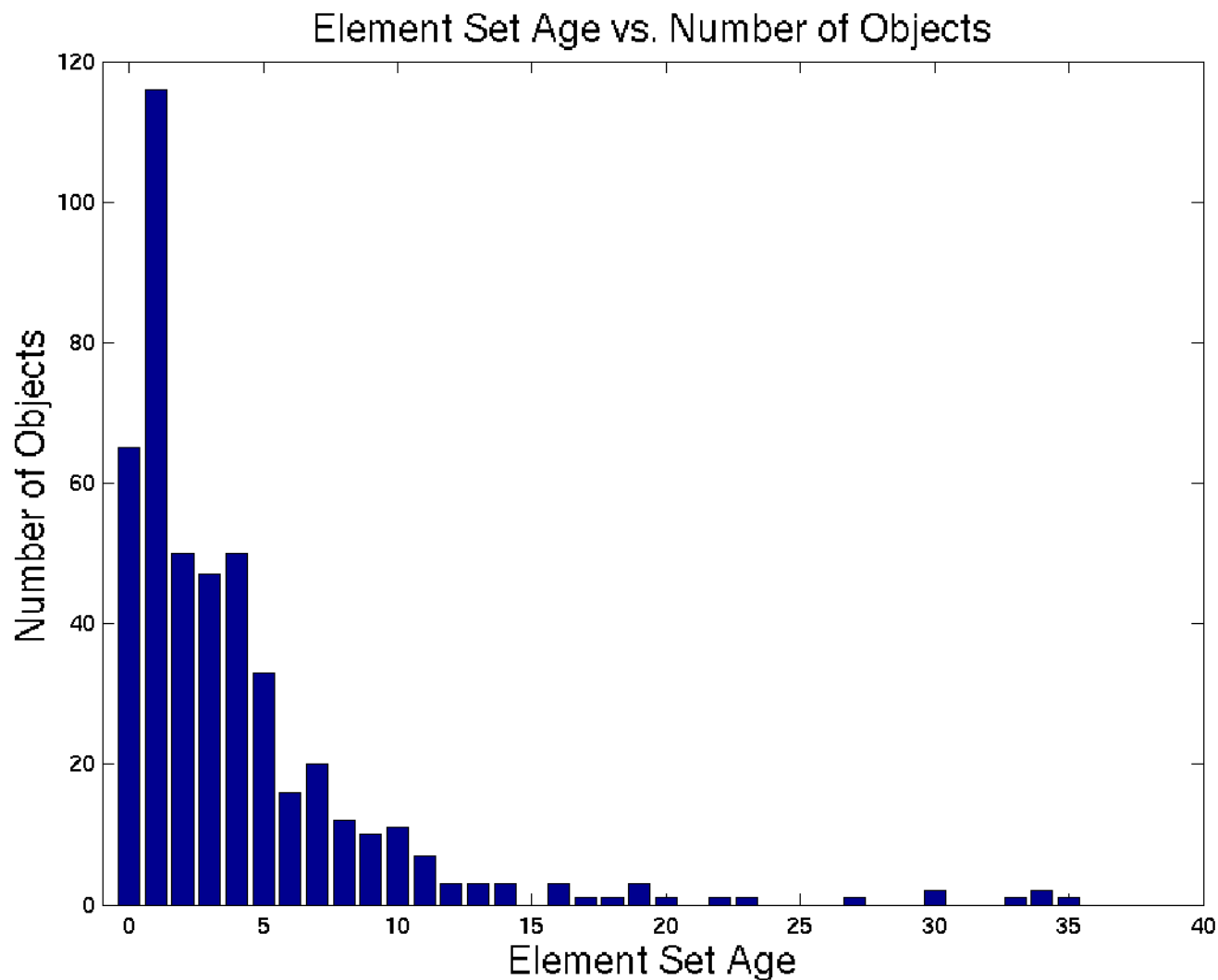
# GMWS Validation

---

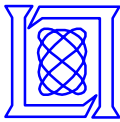
- **GMWS system runs daily**
  - Updates orbits based on new tracking
  - **Generate ALERTS and WARNINGS**
  - Generates necessary tasking to improve encounter estimation
- **A number of system checks are made to ensure that all components are running properly**
- **Validating the results:**
  - Examine age of element sets
  - Examine orbit and encounter prediction accuracy
    - Orbits overlapped over semi independent (10% overlap) fit spans
    - Predicted orbit accuracy assessed by predicting backwards
  - Track with radar during closest approach to confirm predicted encounter distance and time



# Element Set Ages for the GMWS Catalogue

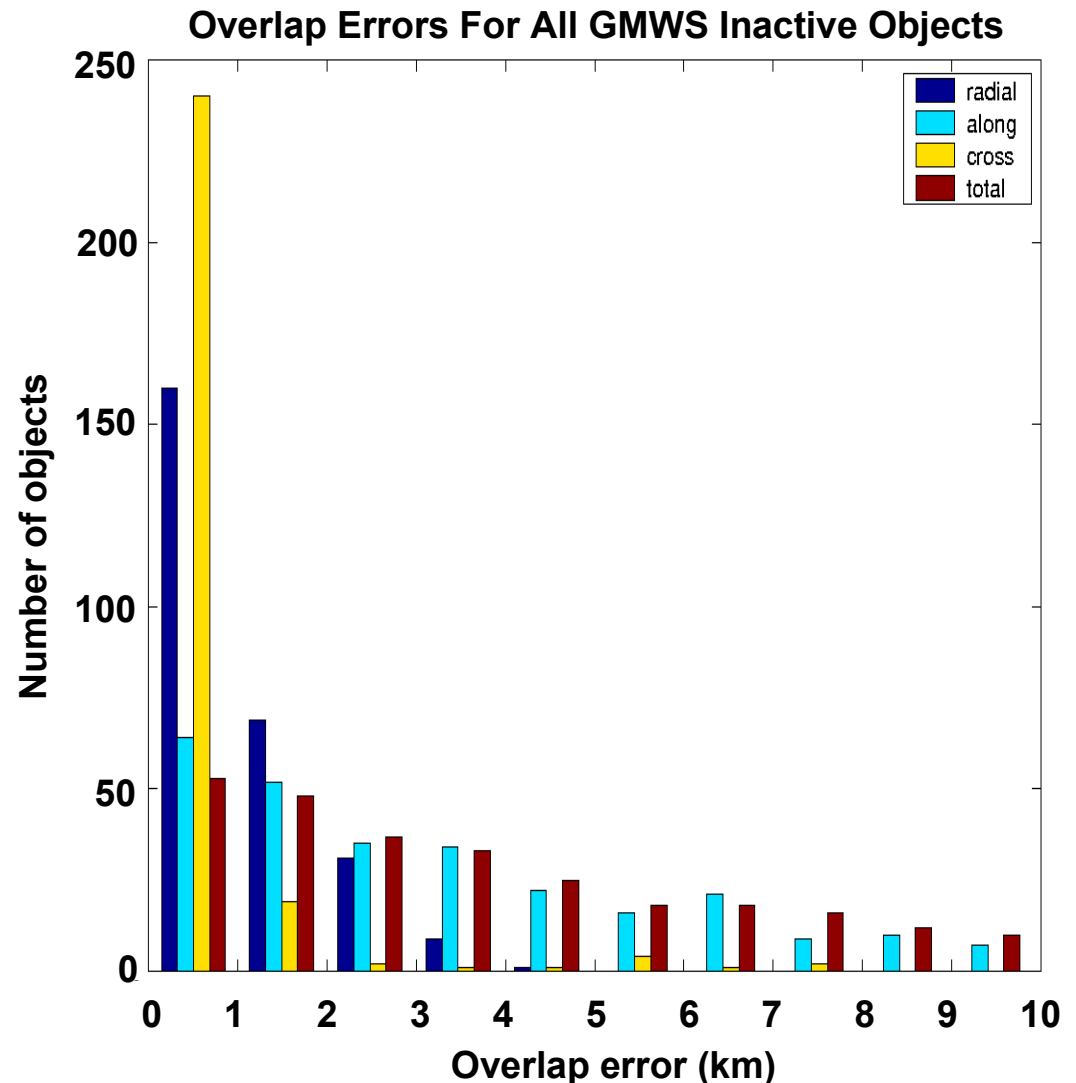


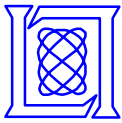




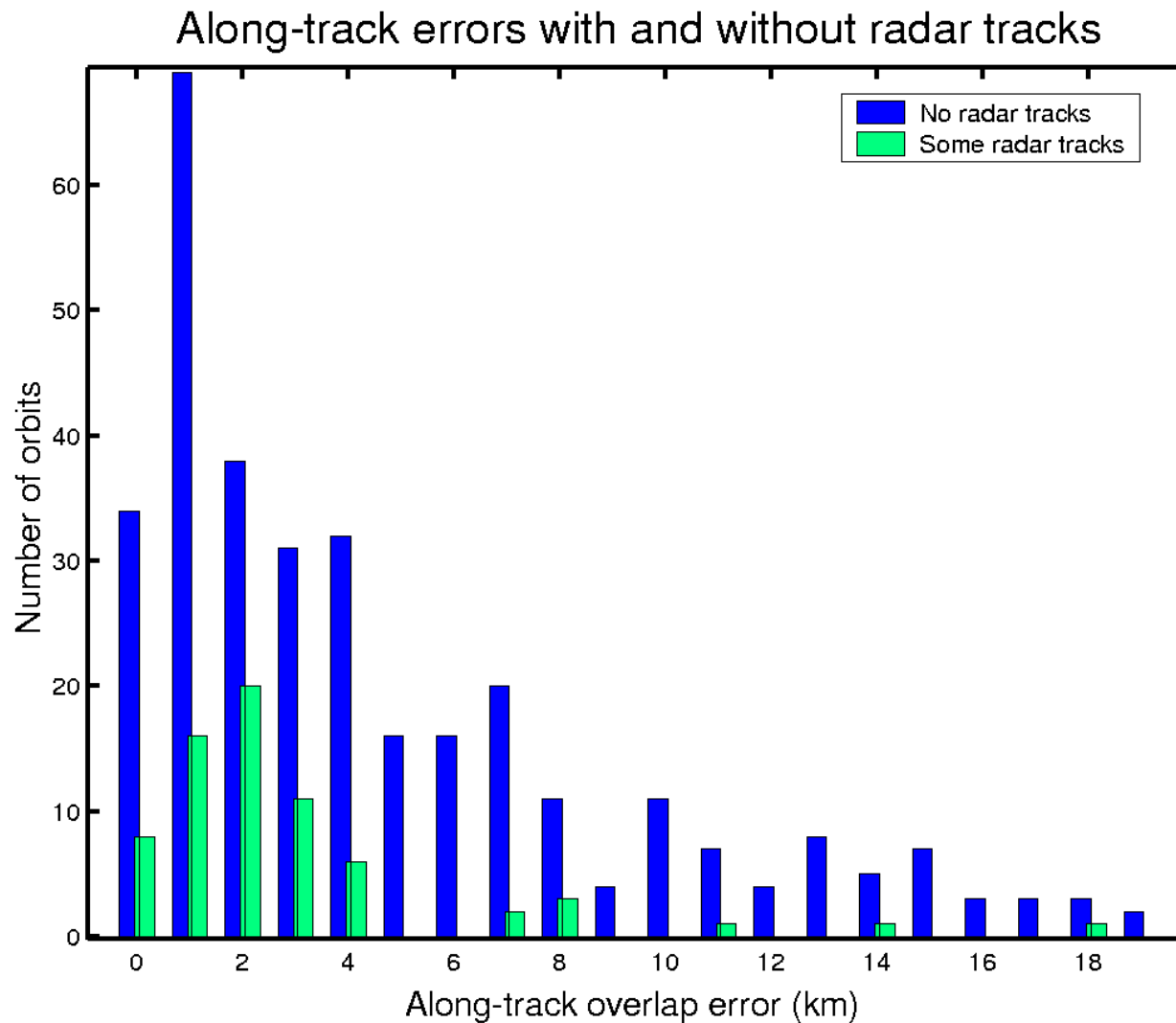
# GMWS: Orbit Accuracies by Overlap

- **GMWS Deep Space Catalog**
  - 477 orbits computed
    - 443 inactive
    - 34 active
  - 472 DYNAMO orbits
  - 408 objects have orbits determined from optical observations only
- **GMWS Inactive Objects**
  - 443 inactive objects
  - 346 (78%) have overlap errors measured
    - 331 (96%) have errors < 50 km
    - 256 (74%) have errors < 10 km
    - 189 (55%) have errors < 5 km
    - 52 (15%) have errors < 1 km



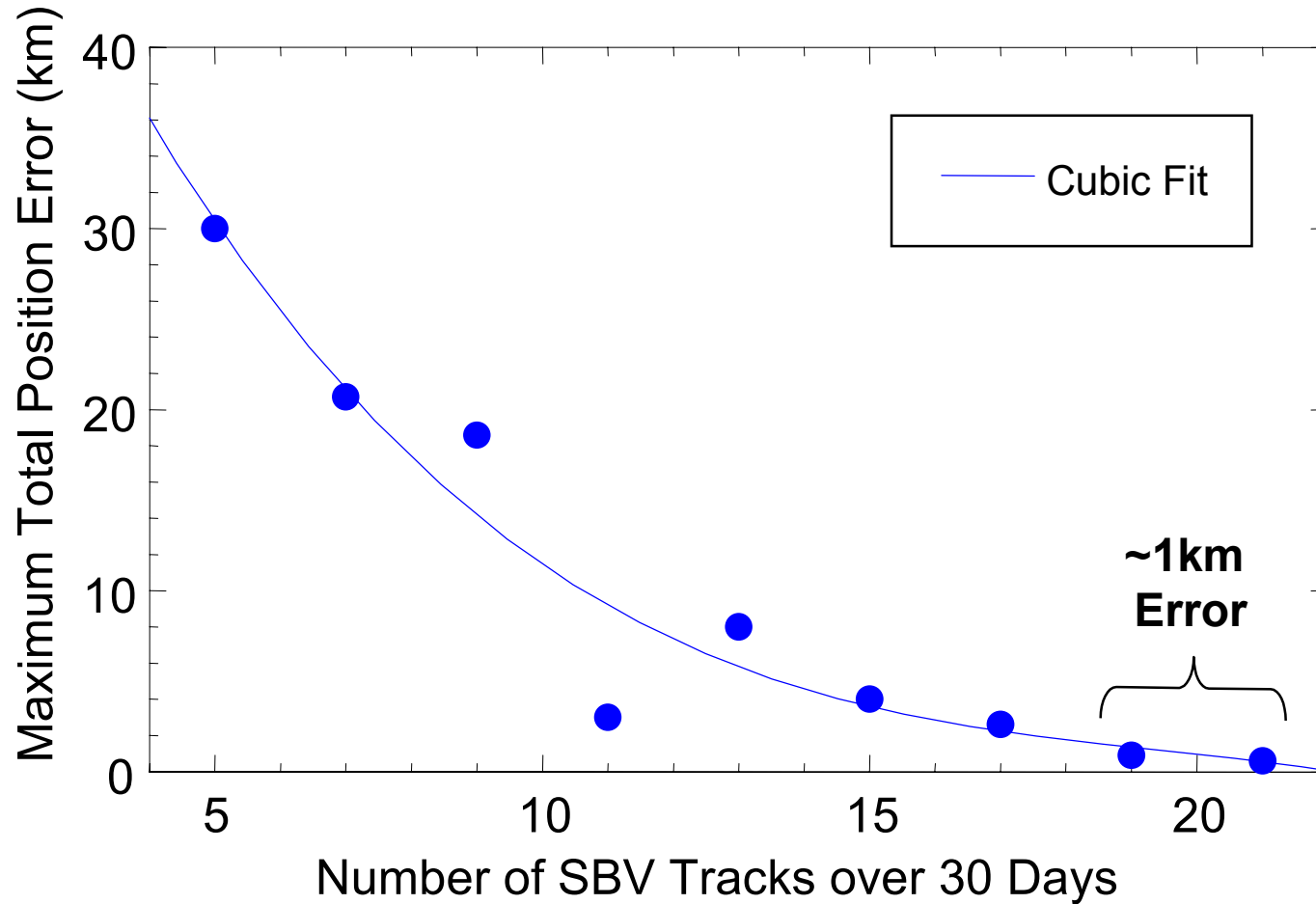


# GMWS Along-Track Error Distribution

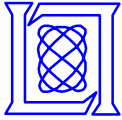




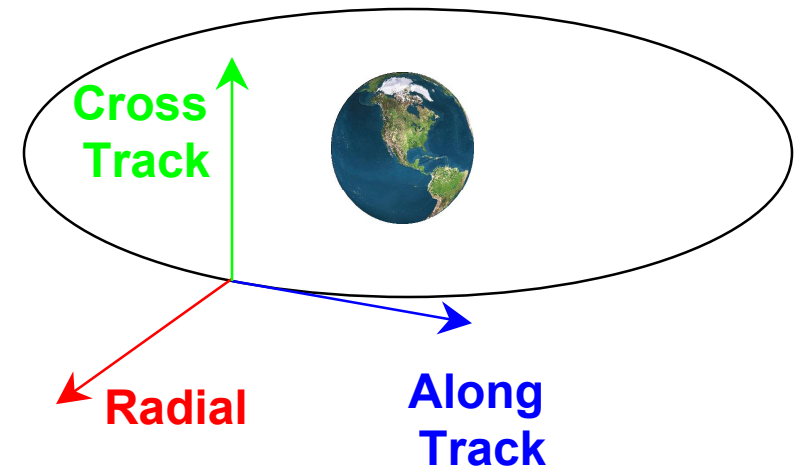
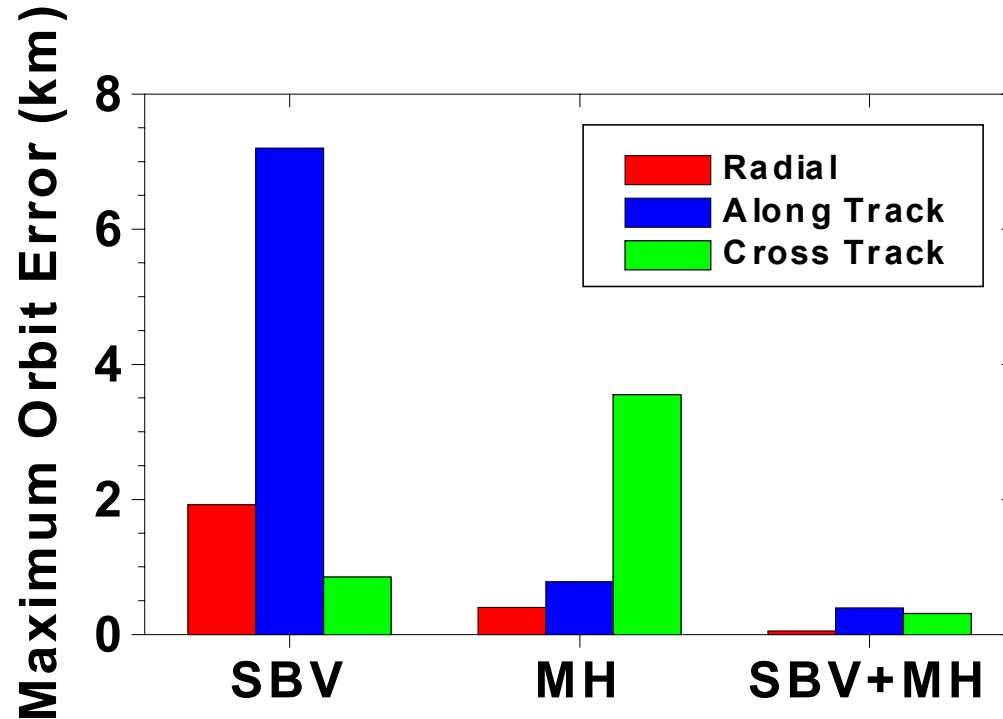
# SBV Only High Accuracy GEO Orbits



**SBV capable of generating high accuracy GEO orbits**



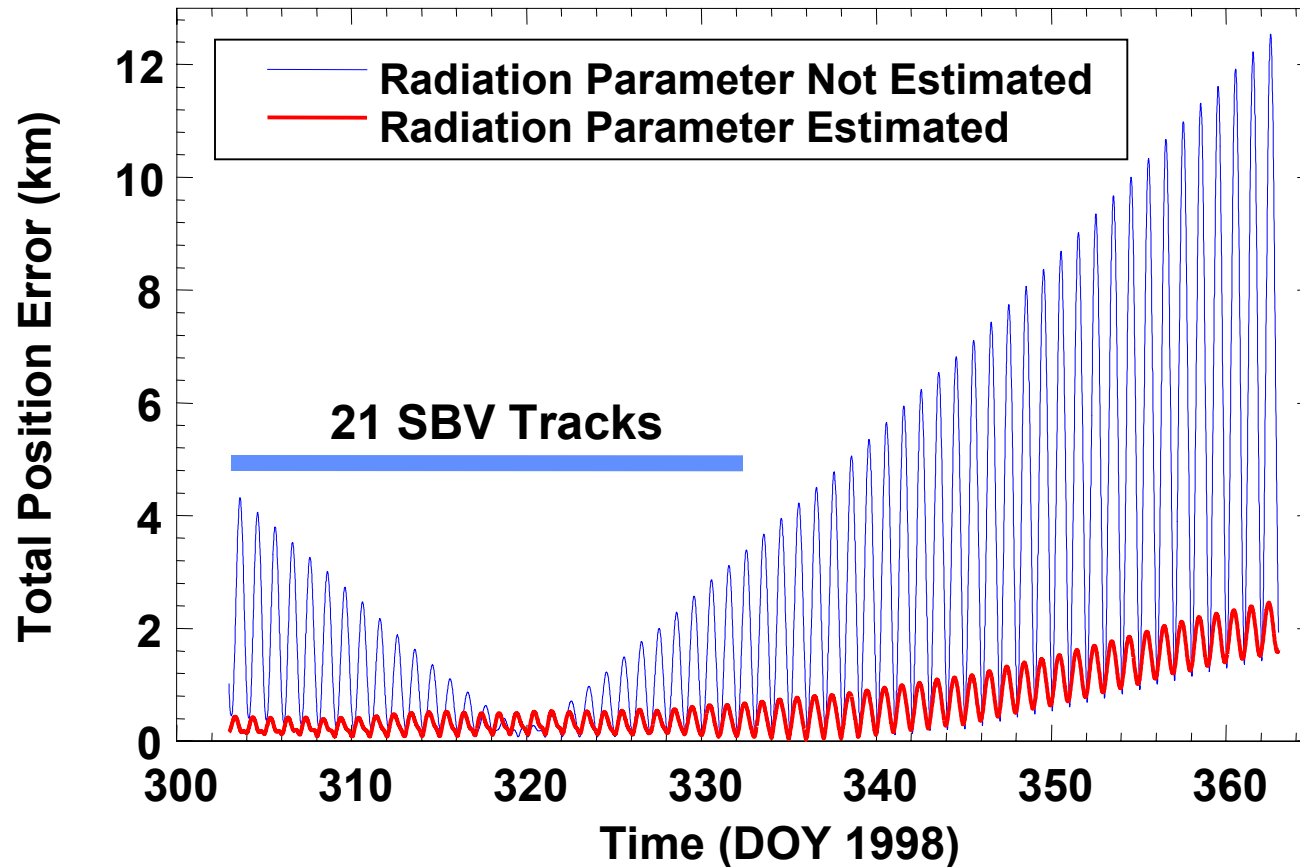
# SBV and Radar Data Fusion



- Two week observation span
  - 6 SBV tracks
  - 3 Millstone (MH) tracks
- Optical and radar data are complementary
- Optimize data collection to achieve a given accuracy



# Effect of Accurate Radiation Pressure Modeling



- Radiation parameter error significant source of prediction error



# Orbit Accuracy Improvement by Adding CRDA Partner Range Data

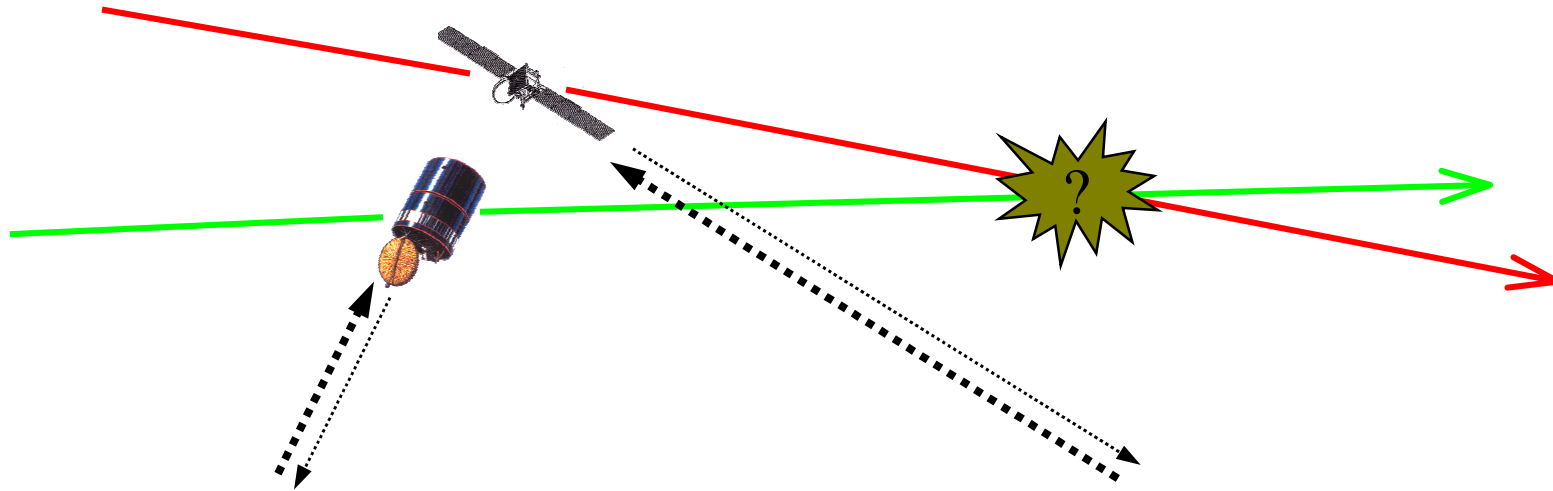
---

Tracking Case	$\Delta$ Rad RMS(m)	$\Delta$ Cross RMS(m)	$\Delta$ Along RMS(m)	$\Delta$ RSS (m)
Millstone Only	132	1236	268	1272
Millstone + Telesat	9	61	17	64

- Orbit Accuracy Assessment of Anik E1 (Telesat Canada) by Overlap



# Encounter Validation With Millstone and Haystack Radars

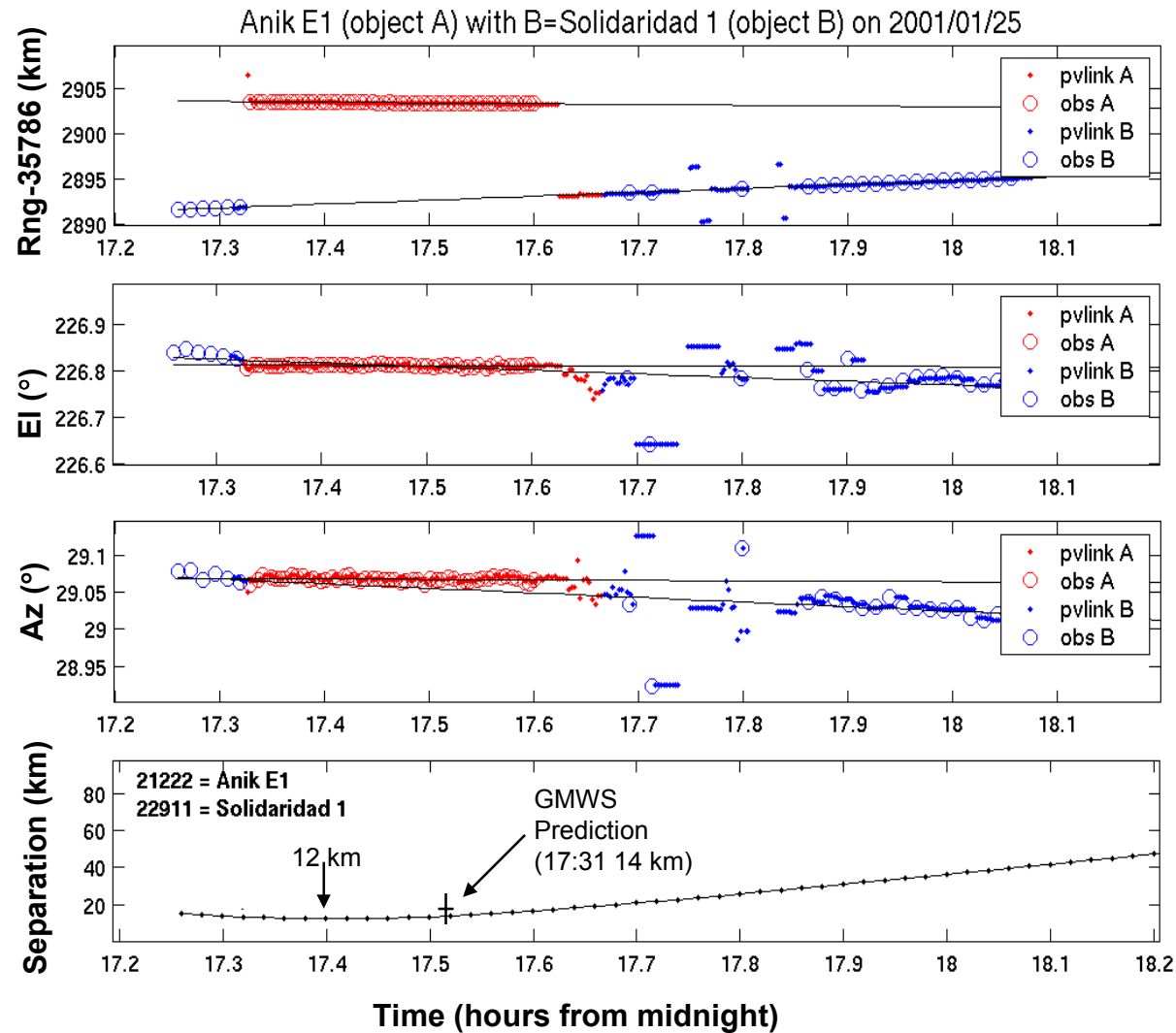


- Millstone and Haystack each track one of the encountering objects
- Observations are later combined, giving a three-dimensional picture of the encounter (in azimuth, elevation, and range)
- If Haystack is unavailable, Millstone alternates between objects

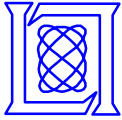




# Single-Radar Encounter Validation







# Summary and Future Work

---

- **GMWS is currently monitoring a catalogue of ~ 450 inactive and 34 CRDA partner satellites**
  - **GMWS generates close encounter ALERTS 60 days out followed by WARNINGS 15 days out**
  - **MHR and SBV tasking requested as needed to enhance accuracy of encounter prediction**
- **Accuracy measures from GMWS currently show 75% with errors < 10 km and 50% with errors < 5 km**
  - **Enhanced using radar, radiation pressure scale factor, longer arcs if optical only**
- **Calibrated CRDA partner range and timely maneuver information important to enhance tracking resources**
- **Accuracy assessment, maneuver detection, active vs. active, and precision longitude monitoring are current priority Research and Development components for GMWS**